DESIGN AND IMPLEMENTATION OF HUMAN CROWD DENSITY ESTIMATION SYSTEM WITH ENERGY HARVESTING IN WIRELESS SENSOR NETWORK PLATFORM

by

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Science is descriptive but not explanatory. Science explains mathematically the behaviour of nature, but it often does not explain why it is so. It is a wonder that the rules of our complex world can be expressed in mathematical terms. Nature seems to present itself in simple numerical ways.

I am purely devoted to the notion that religion and science are at harmony. God made the nature in a level that human minds can comprehend. And God answered the basis of the ‘why’ and ‘what’ questions through religion.

All praise to the One true God; the Most Gracious and Merciful. God, the Creator of all things seen and unseen, the Creator of the biggest of things; the ‘Arsh, to the smallest of things; the quarks?, the Creator of life and death, and Most Supreme is His Knowledge and Power. It is by His Will that I have travelled this journey of knowledge enrichment. And I take this utmost opportunity to thank God.

Peace and blessings upon Prophet Muhammad, the Seal of the Prophets. Prophet Muhammad is a blessing to the entire world. He is a man sent for humans to follow towards the straight path. For if a prophet was sent as an Angel, woe to us for we will not be able to exemplify an essence that is not the same as ours. Such is the Wisdom of God, the All-Knower.

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TABLE OF CONTENTS

CHAPTER THREE: METHODOLOGY

CHAPTER FOUR: IMPLEMENTATION AND EXPERIMENTATIONS OF THE PROPOSED SYSTEM

CHAPTER FIVE: RESULTS AND DISCUSSIONS

LIST OF PUBLICATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
APS	Application Support Sub-layer
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
AT	Transparent
BLE	Bluetooth Low Energy
BMS	Battery Management System
CSI	Channel State Information
CSMA-CA	Carrier Sense Multiple Access - Collision Avoidance
DMM	Digital Multimeter
DOE	Design of Experiments
DSSS	Direct Sequence Spread Spectrum
DS	Dynamic Human Crowd and Static Receiver
EH	Energy Harvesting
EM	Electromagnetic
EN	End Node
ETSI	European Telecommunications Standards Institute
FHSS	Frequency Hoping Spread Spectrum
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
H-CDE	Human Crowd Density Estimation
HD	High Density
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IC	Integrated Circuit

ICNIRP	International Commission on Non-Ionizing Radiation Protection
ID	Identification
IoT	Internet of Things
ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
I-V	Current versus Voltage
LD	Low Density
Li-ion	Lithium ion
LAN	Local Area Network
LOS	Line-of-Sight
LQI	Link Quality Indicator
MAC	Medium Access Control
MANET	Mobile Ad Hoc Network
MD	Medium Density
MPPT	Maximum Power Point Tracking
MSK	Minimum-shift Keying
MTU	Maximum Transmission Unit
NLOS	Non-Line-of-Sight
ODFM	Orthogonal Frequency Division Multiplexing
PAN	Personal Area Network
PC	Personal Computer
PC-ABS	Polycarbonate - Acrylonitrile Butadiene Styrene
PHY	Physical
PMU	Power Management Unit
PSDU	Physical Service Data Unit
PV	Photovoltaic
QFN	Quad-Flat No-Leads

RF	Radio Frequency
RFID	Radio Frequency Identification
RP-SMA	Reverse Polarity-SubMiniature version A
RSSI	Received Signal Strength Indicator
RTOS	Real-Time Operating System
RX	Receiver
S	Static Human Crowd and Receiver
SCPL	Sequential Counting, Parallel Localizing
SD	Secure Digital
SPI	Serial Peripheral Interface
S1	Series 1
S2	Series 2
T-R	Transmitter and Receiver
TX	Transmitter
UART	Universal Asynchronous Receiver/Transmitter
USA / US	United States of America
USB	Universal Serial Bus
WBAN	Wireless Body Area Network
Wi-Fi	Wireless Fidelity
WISP	Wireless Identification and Sensor Platform
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

REKA BENTUK DAN IMPLEMENTASI SISTEM PENGANGGARAN KEPADATAN MANUSIA DENGAN PENUAIAN TENAGA DALAM PLATFORM RANGKAIAN PENGESAN TANPA WAYAR

ABSTRAK

Kepadatan yang tinggi dalam khalayak ramai boleh menjadi berbahaya kerana wujudnya potensi untuk pergerakan sekumpulan manusia secara tiba-tiba yang menyebabkan rempuhan dalam kes kecemasan. Untuk mengurangkan kecederaan mahupun kehilangan nyawa dalam kemalangan yang berkaitan dengan isu kepadatan manusia, sistem pengawasan kepadatan manusia berdasarkan frekuensi radio telah dibangunkan sebagai satu alat keselamatan. Sistem yang didapati pada masa kini mempunyai keupayaan pengawasan yang terhad; saiz pengawasan khalayak yang rendah, jarak pengesanan yang rendah, keperluan bilangan alat komunikasi yang tinggi dan jangka hayat operasi yang terhad. Faktor-faktor ini memberi kesan secara langsung kepada unsur praktikal dan ketepatan sistem penganggaran kepadatan manusia tersebut. Untuk mengurangkan kelemahan keupayaan pengawasan, satu sistem untuk mengesan kepadatan khalayak diusulkan berdasarkan kepada teknologi ZigBee dan rangkaian pengesan tanpa wayar yang meningkatkan jarak pengesanan khalayak kepada 30 m dengan hanya satu nod diperlukan setiap 37.5 m^2. Hal ini dicapai tanpa mengurangkan bilangan khalayak (50 orang) yang boleh dikesan oleh sistem. Untuk menambahbaik ketepatan anggaran, kesan khalayak terhadap isyarat diselidik menggunakan kaedah statistik ‘One-way Analysis of Variance’ dan ‘Design of Experiments’. Hasil dapatan mengesahkan saiz khalayak memberi kesan yang paling besar terhadap kelemahan isyarat. Untuk interaksi di antara sifat-sifat khalayak, didapati saiz khalayak bersama bilangan alat penerima dan bentuk khalayak bersama bilangan alat penerima memberi kesan signifikan terhadap kekuatan isyarat. Faktor-faktor ini kemudian dimasukkan ke dalam algoritma H-CDE yang diusulkan. Algoritma pengesanan khayalak ini dan pengelasannya menunjukkan purata sebanyak 71.2 peratus ketepatan dalam mengenalpasti tahap kepadatan khalayak yang juga dapatan terbaik berbanding algoritma lain. Untuk mengatasi masalah kuasa yang terhad, mekanisma tuaian tenaga solar diperkenalkan ke dalam sistem H-CDE untuk memanjangkan jangka hayat operasi pengawasan. Kajian menunjukkan mekanisma tuaian tenaga ini mampu untuk memanjangkan operasi sistem pengawasan secara berterusan jika sistem ini mendapat paling kurang 5 hingga 6 jam pendedahan kepada sinaran matahari setiap 33 jam kitaran. Sumbangan kajian ini ialah pada penambahbaikan sistem berdasarkan teknologi frekuensi radio untuk mengesan kepadatan khalayak, penambahbaikan pada ketepatan penganggaran kepadatan khalayak yang didokongi oleh analisis statistik dan lanjutan operasi sistem melalui mekanisma tuaian tenaga.

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ABSTRACT

A crowd with high density can be dangerous due to the potential of a sudden surge of large moving bodies causing stampede in cases of emergencies. To mitigate casualties in crowd-related disaster, radio frequency-based crowd density estimation and monitoring system is being developed as a safety tool. Current systems have limited monitoring capabilities; low size of crowd monitored, low detection range, high number of transceivers required and finite operational lifetime. These factors directly influence the practicality and prediction accuracy of the system. To mitigate the limited sensing capability, a human crowd density estimation (H-CDE) system based on ZigBee and wireless sensor network technology is proposed that increases the crowd detection range to 30 m with only one transmission node required every 37.5 m^2. This is achieved without sacrificing the amount of crowd detectable by the system (50 people). To improve the estimation accuracy, the effect of crowd on signal propagation is investigated using One-way Analysis of Variance and Design of Experiments statistical methods. The results verified that the crowd size significantly affects the signal attenuation. In the interactions between the crowd properties, crowd size * number of receiver and crowd pattern * number of receiver were found to significantly affect signal propagation. These factors are then integrated into the proposed H-CDE algorithm. The H-CDE algorithm and its crowd classification yielded an average of 71.2 % accuracy in identifying the level of crowd density, which is the best compared to other algorithms found in the literature. To solve the finite power problem, a solar energy harvesting mechanism is introduced into the H-CDE system to extend the operation of the monitoring system. It is demonstrated that the proposed energy harvesting mechanism could operate perpetually, given that the system is exposed to good sunlight at least for 5 to 6 hours

in every 33-hour cycle. The contribution of the research is on the improved RF-based crowd density detection system, improved crowd estimation accuracy which is backed by statistical analysis and extension of its operations through the energy harvesting mechanism.

CHAPTER ONE
INTRODUCTION

1.1 Background

Human crowd density estimation (H-CDE) is used to predict the magnitude of human concentration in an area. Understanding about the crowd itself is known as crowd science, whereas the estimation effort is an engineering problem and agenda. A highly crowded area has great potential for injuries and accidents. Thus, H-CDE is important to manage human safety and reduce crowd-related disasters.

Conventional H-CDE systems are based on visuals captured from CCTV. The problem with CCTV is that it is resource extensive in terms of labour and financial cost. On the other hand, radio frequency (RF)-based crowd monitoring system could complement the existing system by offering automated and flexible operation.

Crowd density estimation using RF is less developed compared to visual-based systems due to problems related to the unpredictable wireless medium. The wireless medium is susceptible to white noise; random signals where all possible frequencies are present in the atmosphere, which may qualitatively and quantitatively affect a transmission. The behavior of wireless propagation in the shape of reflection, diffraction and scattering, in addition to absorption and multipath, has also created significant problems and challenges to overcome.

Improved techniques have been developed that shows that the RF-based crowd estimation is feasible. The works of Morrison, Bell and Chalmers (2009), Mowafi, Zmily, Abou-Tair and Abu-Saymeh (2013), Yuan, Zhao, Qiu and Xi (2013), Weppner and Lukowicz (2013), Xu et al. (2013), Weppner, Lukowicz, Blanke and Troster (2014), Xi et al. (2014), Yuan (2014), Haochao et al. (2015) and Hiroi, Shinoda and Kawaguchi (2016) on H-CDE is examined. Furthermore, as the H-CDE system requires wireless sensing, the Wireless Sensor Network (WSN) platform is normally adopted as the foundation of the